An Efficient Way to Harness the Sun's Power

SOLAR energy technologies have been around for ages. Since the discovery that sunlight passing through glass would start a fire, humans have been searching for methods to harness the Sun's radiant energy. Technologies that exploit solar energy are quite important in the modern world because, unlike fossil fuels, the Sun is a renewable, sustainable energy source.

Today, photovoltaic solar panels combined with electric batteries provide energy to power electronic devices, homes, and even the International Space Station. However, widespread use of the Sun as a primary energy source is hampered by two main factors. Solar electricity is expensive when compared to the cost of power produced by burning fossil fuels, and sunlight is intermittent—the Sun's energy can only be collected during daylight hours.

To address these problems, Livermore scientist Charles Bennett is developing a solar thermal technology that takes a new approach to storing and using the Sun's energy. Called GyroSolé™, the heat-powered engine and thermal-energy-storage system collects solar energy and stores it as unrefined heat instead of refined electricity.

Storing energy in the form of heat is particularly advantageous because most power consumption is devoted to thermal management—to heat and cool our homes, the food we eat, and the water we use throughout the day. In California, for example, approximately 85 percent of the total energy used in the average residence is devoted to thermal management rather than power generation. Because of this dominance, the thermal energy emerging from a heat-powered engine may be so well matched to the energy needs in a typical home or business that almost none of this heat need be wasted.

A Recovery Plan for Waste Heat

With the conventional electrical grid, centralized power plants transport electric power over wires, which often run hundreds of kilometers before reaching the business and residential areas that consume electricity. These power plants operate by burning fossil fuels to generate heat that is then refined into electricity. The refinement process produces a great deal of thermal energy that is not distributed as electricity. Containing this heat for transport over a long-distance network would be too expensive to implement, so instead, power plants reject it, sending it to cooling towers that disperse it to the environment. The magnitude of the rejected energy is significant. In 2007, the U.S. alone lost almost 60 percent of the energy produced at power plants.

GyroSolé takes advantage of the waste heat to provide heating, cooling, and electricity independent of the grid. Rather than relying on centralized power plants with long-distance transmission and distribution networks, consumers would install the generator where energy is consumed—at their homes or businesses. The system would be particularly advantageous in remote locations, where a conventional network would be too expensive to build. It also could send any extra power to the grid, helping to further reduce fossil-fuel consumption.

Bennett estimates that GyroSolé can supply electric power for about six cents per kilowatt-hour and heating for two cents per kilowatt-hour. In contrast, the current retail price for residential electric power is about 10 cents per kilowatt-hour. Photovoltaic solar power would be even more expensive without government subsidies, plus solar panels do not directly produce heating or cooling.

GyroSolé was inspired by a concept for powering an aircraft through the night with solar energy collected during the day.

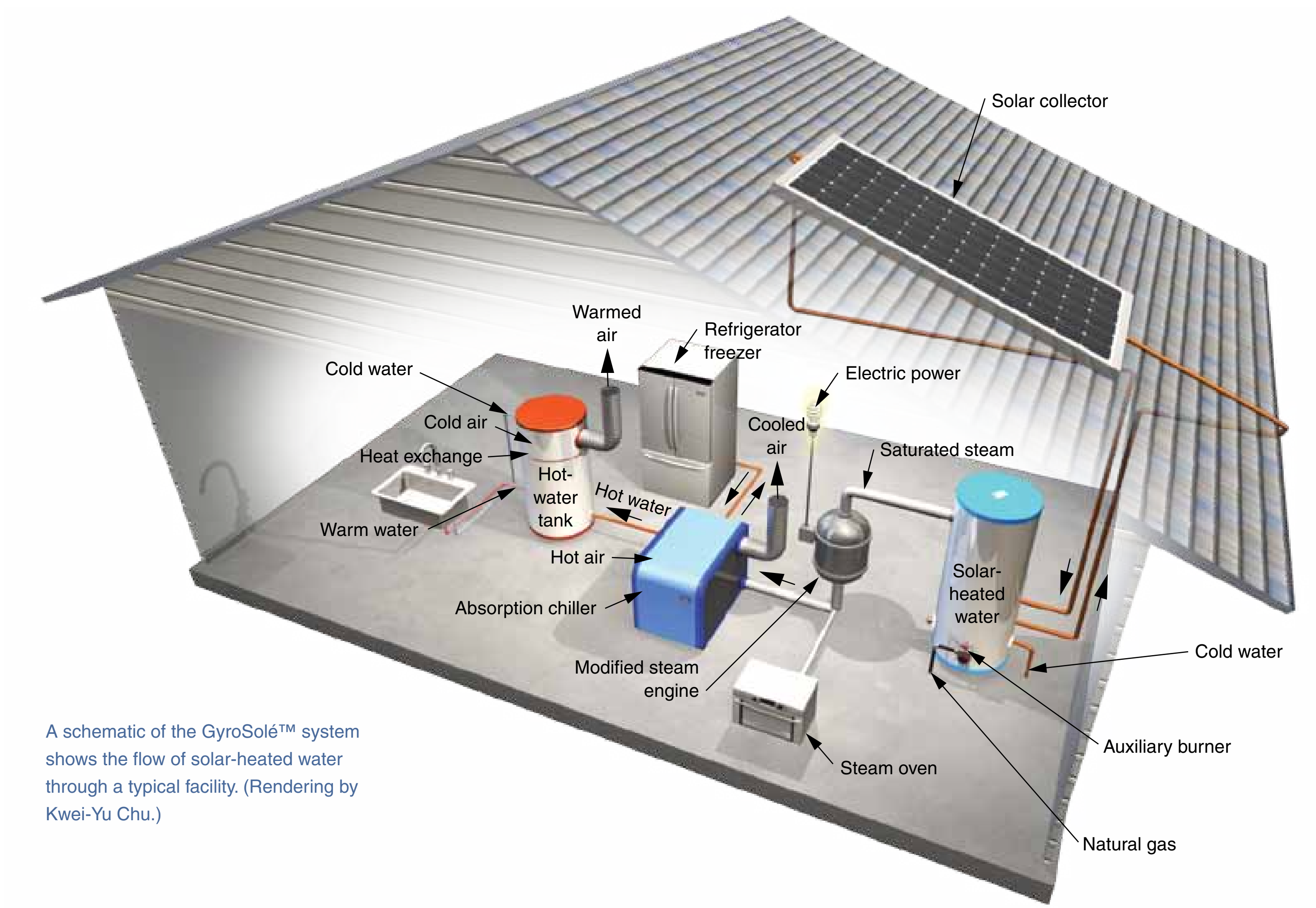
Key issues for the solar-powered aircraft were energy storage and efficiency to ensure that power was available through a 24-hour cycle. The solar aircraft project led to innovations that Bennett adapted for the residential application, which was initially funded by Livermore's Laboratory Directed Research and Development Program.

SUNsational Energy Technology

A key component of GyroSolé is the steam engine that drives the system's electric generator. The engine is a hybrid of old and new technologies, combining a reciprocating steam engine with some modern internal combustion engine parts and harmonic oscillator valves. "This design eliminates much of the mechanical gear used to actuate the valves in conventional reciprocating engines, which reduces the efficiency in those systems," says Bennett. The harmonic engine is tailor-made to deliver power at a fixed frequency, such as 60 hertz, and it operates with saturated steam, instead of the superheated steam required to protect the blades of conventional steam turbines. As a result, GyroSolé will attain the highest possible thermal efficiency for its temperature range of operation.

The GyroSolé system (shown in the figure below) is designed for the typical variations in power consumption, especially in winter, when demands for heat increase at night, while those for electricity are highest during the day. A solar collector traps radiant energy while the Sun is shining and uses it to heat water in boiler tubes. Steam from these tubes is apportioned between the modified steam engine, for immediate power production, and a hot water tank for later use. Consumers may also choose to install an auxiliary heating system powered by natural gas to have a backup energy source during periods of inadequate sunlight.

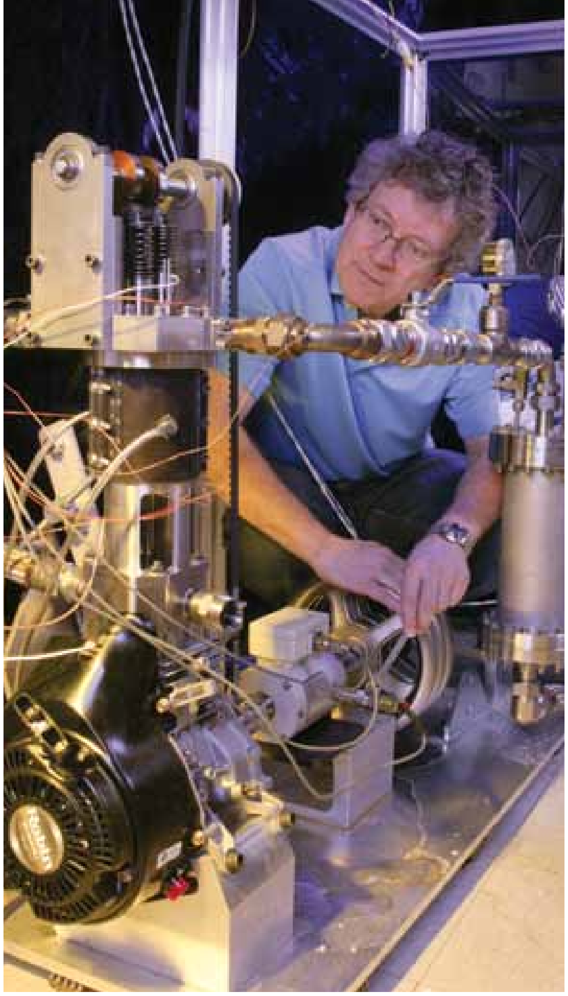
In a typical application, water is heated to about 180°C, which produces a pressure of 10 atmospheres, or 1 megapascal. Spent steam emerging from the engine at about 100°C and 1 to



A schematic of the GyroSolé™ system shows the flow of solar-heated water through a typical facility. (Rendering by Kwei-Yu Chu.)

2 atmospheres of pressure is available for various uses. It may pass through a steam-driven absorption chiller to provide cooling for air conditioning or refrigeration, or it may be condensed to produce hot water or heat for other purposes.

To test some of the GyroSolé components, Bennett built a laboratory-scale prototype steam engine using parts from a commercial gasoline-powered internal combustion engine. (See the figure at right.) Because the steam engine is clean enough to deliver potable water, GyroSolé is safe to use for cooking. Water not consumed in cooking, washing, or other domestic chores emerges at just above room temperature, and thus almost all of the collected solar energy is used.



Livermore physicist Charles Bennett checks out the laboratory-scale prototype steam engine, which is a key part of the GyroSolé system he designed. The prototype couples the crankcase of a commercial gasoline-powered engine to a custom steam expansion cylinder.

A Truly Bright Idea

Livermore's Industrial Partnerships Office (IPO) is using GyroSolé and another Livermore device—the flywheel battery developed by physicist Dick Post—in a different type of beta test: working with facilities to showcase Laboratory-developed technologies. Under a grant from the Department of Energy's Energy Efficiency and Renewable Energy Office, IPO is partnering with the Arc of Hilo, a nonprofit organization on the island of Hawaii, to integrate the two clean-energy technologies into the Hilo plant's food-processing operations.

"An important step in technology maturation is putting a prototype to work," says Annemarie Meike, a business development executive in IPO. "In the Arc of Hilo collaboration, we're focusing on specific applications. That way, we can see how the systems look in operation and more quickly identify ways to improve them."

The Arc of Hilo has leased a 1,700-square-meter warehouse where local farmers can develop food products, such as fruit leather, jams, and natural sweeteners. The plant will integrate both Livermore technologies into the food-processing scheme, which could reduce its electric bill by 50 percent. "Hawaii is a logical place to start," says Bennett. "The seven-island state imports the fuel it uses to generate power and thus has one of the highest electricity rates in the nation."

The Hilo plant is an especially good match for GyroSolé because food processing requires all facets of thermal management: cooling for refrigeration and air conditioning; heating for cooking, cleaning, and space heating; and electric power to operate the plant's equipment. In addition, excess electricity generated at the plant will be delivered to the Hawaiian power grid.

Meike adds that the collaboration offers benefits for everyone involved. "Our licensing partners can build production-scale applications that showcase their products incorporating the Laboratory's technologies," she says. "At the same time, our inventors have the opportunity to develop their ideas into working technologies with specific requirements even before the commercial application of ultimate interest to the licensee is in full production. In our beta test for this type of technology showcase, the Arc of Hilo is bringing a new resource to the island—one that will help create jobs and reduce the cost for developing food products."

Bennett hopes the GyroSolé system will expand the use of solar energy technologies. "A reliable solar heating system can save energy, reduce utility costs, and produce clean energy," he says. "This technology encourages the transformation of global energy production from a fossil-fuel-dominated architecture to one that is both indefinitely sustainable and free from greenhouse-gas production."

For GyroSolé, the future holds many sunny days.

—Kristen Light

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